DESIGN OF A DEFORMED FLAT PLATE TO COMPENSATE THE GAIN LOSS DUE TO THE GRAVITY-INDUCED SURFACE DISTORTION OF LARGE REFLECTOR ANTENNAS

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Abstract:: This paper presents a novel design of a deformed flat plate, wherein known amounts of distortion are introduced in a compensating flat plate, to recover the gain-loss due to gravity-induced surface deformations of a large reflector antenna. Geometrical-optics (GO) principle is used in the design. The deformed flat plate has been realized by actuators controlled by stepper motors. Diffraction analysis performed on the system demonstrates the validity of the technique.

INTRODUCTION

Gravity-induced surface distortions on large reflector antennas can affect their electrical performance significantly. In the case of the 34-meter NASA/JPL's Deep Space Network antenna, the gain loss due to such a distortion is significant at Ka-band frequencies. The reflector panels have been set such that at 45° elevation angle, the reflector shape is close to the ideal designed shape after accounting for the gravity effect. However, for extreme elevation angles of 0° and 90°, the gain-loss due to gravity-induced shape distortion is found to be 2.4 dB and 1.5 dB respectively. Our prior investigation showed that the conventional array feed compensation is not desirable since it would require a large number array elements, thus making such a system prohibitively expensive. In this paper we describe a novel technique using a deformed flat plate. The antenna is a dual-shaped reflector system and it is fed by a beam waveguide consisting of a series of six mirrors as shown in Fig. 1. The nominally flat plate M6, the last mirror close to the RF front end will be deformed to compensate for the gain-loss.

ANALYSIS

For a plane wave incident on the main reflector, the physical-optics (PO) currents induced on the sub-reflector are determined via the GO approach. PO integration method is used to find the scattered fields and the induced currents in the subsequent reflectors by considering a pair of reflectors at a time. Thus eventually the currents on M6 are obtained for the case of undistorted and distorted main reflectors for each elevation angle. Since the gravity-induced distortion is small and slowly varying, the gain loss is primarily due to phase errors. The mirror M6 is divided into a large number of planar triangular segments such that each is about 0.125 λ^2 area, where λ is the wavelength. The phase error at any triangular segment M6 is the difference between the phase values of the currents for the undistorted and distorted main reflector calculations. The phase error is translated into a path length based on GO consideration. This algorithm modifies the flat surface into a large number of stepped segments. Subsequently a global polynomial representation is used to convert this deformed stepped mirror into a smooth surface.

The deformed mirror M6 scatters the fields into a collecting aperture, a 23 dB gain horn at the bottom. At the center of M6 the incident and reflected rays make an angle of 30° with respect to the surface normal. The beam waveguide system was originally designed to have an optimum performance at X-band by defocusing the system by 9 in. At 33.67 GHz, the optimum value of the gain of the overall system was achieved by properly choosing the location of the phase center of the horn at a distance of 31.5 in. from the center of M6. It is not surprising that a shift of 1.5 in. in the location of the horn compensates for the 9 in. axial defocusing, since the wavelength is only 0.35 in. Table 3 shows the computed values of gain for the complete system including the dual-reflector, beam waveguide mirrors, and the horn for different elevation angles without and with the DFP compensation technique. The gain values computed in the transmit and receive mode were found to be in good agreement. From the results given in Table 3 we find that the DFP compensation system, used in place of the flat mirror M6, is able to recover almost all the gain-loss. In the worst case we fail to recover only about 0.23 dB at 0° elevation.

Figs. 2 through 4 show linearly polarized far-field radiation patterns of the 34-meter reflector antenna for three elevation angles. Fig. 2 shows the pattern for the 45° elevation angle. For this elevation angle there is no gravity-induced distortion, and hence, there is no compensation. The two patterns are identical for this case. The first side-lobe is found to be close to –17.6 dB of a uniform circular aperture since the reflector was shaped for a nearly uniform aperture distribution and maximum gain. Figures 3 and 4 show the patterns for 0°, and 90° elevation angles respectively. For these two cases the patterns of the distorted main reflector without compensation (flat mirror M6) and with the DFP compensation system are shown. The patterns of the distorted main reflector without compensation show high sidelobe levels including shoulders, and reduced gain values. DFP compensation system produced dramatic improvements in the pattern shapes by bringing them very close to the undistorted pattern, thus validating the compensation technique.

CONCLUSION

A novel method based on geometrical optics principle, of designing a deformed flat plate, has been found to be capable of recovering almost all the gain-loss. The validity of the method has been demonstrated by means of a number of computations such as the agreement between transmit mode and receive mode gains computed, far-field radiation patterns, and plots of beam spot sizes for the distorted and compensated cases. Bruno et al. [2] have demonstrated that such a system may be implemented by only 16 stepper motor actuators to realize the required surface shape within a root mean square (RMS) error of 0.007 in.

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REFERENCES

[1] Cramer, Jr., P. W., W. A. Imbriale, and S. R. Rengarajan, "A method using focal plane analysis to determine the performance of reflector antennas," International Conference on Antennas and Propagation, (ICAP-97), Edinburgh, U. K., Apr. 1997.

[2] Bruno, R., W. Imbriale, M. Moore, and S. Stewart, "Implementation of a gravity compensating mirror on a large aperture antenna," AIAA Multidisciplinary Analysis and Optimization, Bellevue, WA, Sep. 1996.

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Table 1. Computed gain values of the reflector and beam waveguide feed system without and with the DFP compensation

Elevation Angle	Gain with a Perfect Flat Plate in dB	Gain with the Deformed Flat Plate in dB
0	78.433	80.727
15	79.635	80.796
30	80.672	80.858
45	80.955	no compensation
60	80.738	80.903
75	80.176	80.866
90	79.475	80.812

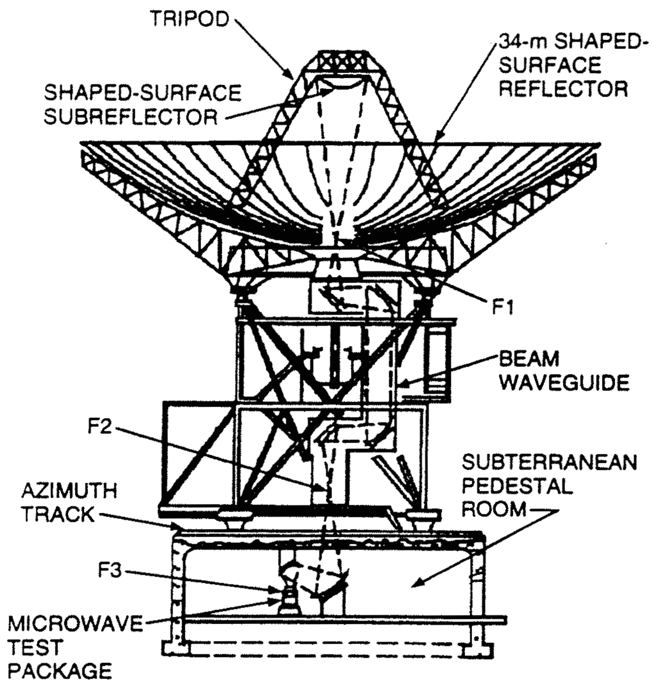

Fig. 1. DSS-13 34-m Beam-Waveguide Antenna.

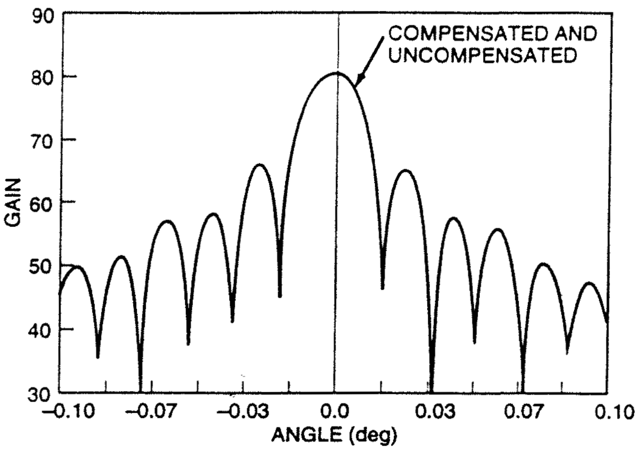

Fig. 2. Compensated vs. Uncompensated for Elevation = 45°.

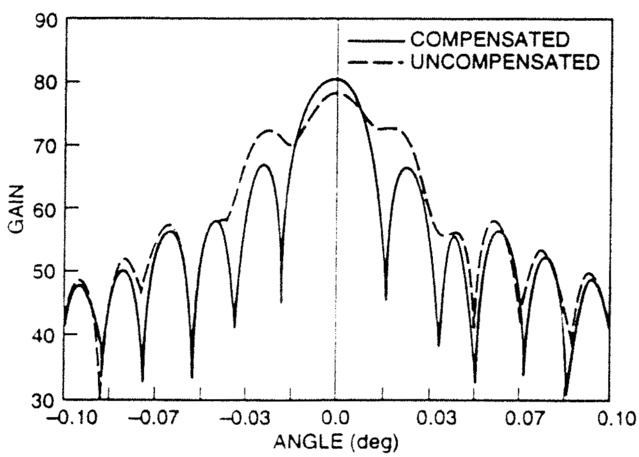

Fig. 3. Compensated vs. Uncompensated for Elevation = 0°.

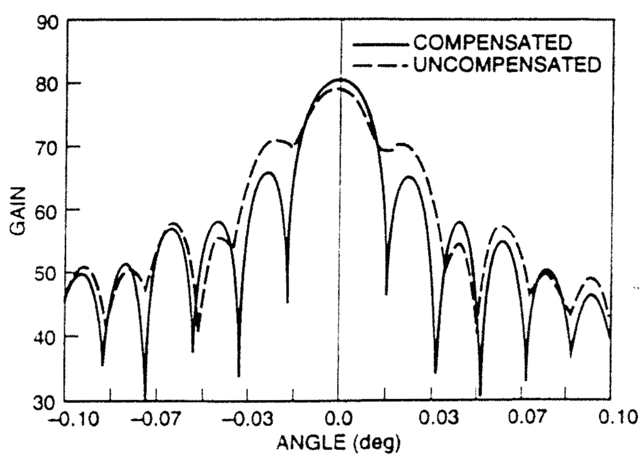

Fig. 4. Compensated vs. Uncompensated for Elevation = 90°.